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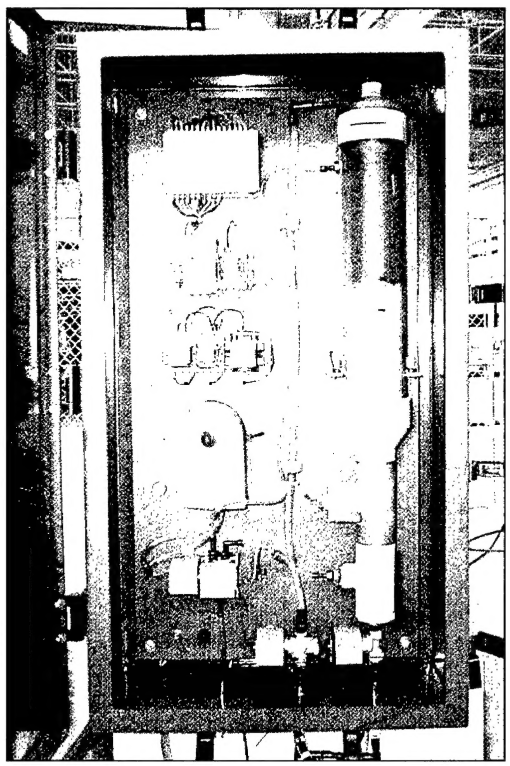
Port Hueneme, California 93043-4370

TECHNICAL REPORT
TR-2191-ENV

OPERATIONAL TEST OF A SENSOR TO DETECT AQUEOUS FILM FORMING FOAM (AFFF) IN SHIP BILGE WATER



by

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A sensor system was developed to detect the presence of foam producing chemicals. The sensor was primarily developed to detect the presence of aqueous film forming foam (AFFF) in bilge water off-loaded from a ship to a shore-side wastewater treatment plant. The foam sensor uses a combination of photo-optical and acoustic range measuring devices to determine the density and height of a column of foam produced by aeration of the wastewater sample. These data are used to estimate the concentration of AFFF in the wastewater sample. The sensor system can detect concentrations of AFFF as low as 10 parts per million (ppm) in approximately 45 seconds. Solutions containing higher concentrations of AFFF are detected in less time. When the concentration of AFFF exceeds a preset value, a switch within the sensor system is closed. The switch closure can be used to perform functions such as:

- Operating a valve to divert the contaminated wastewater stream to a storage tank
- Closing a valve to the lift station sump to prevent further discharge by the ship
- Alert treatment plant operators to take corrective action, such as diluting the incoming steam to lower the concentration of AFFF.

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EXECUTIVE SUMMARY

A sensor system was developed to detect the presence of foam producing chemicals. The sensor was primarily developed to detect the presence of aqueous film forming foam (AFFF) in bilge water off-loaded from a ship to a shore-side wastewater treatment plant. The foam sensor uses a combination of photo-optical and acoustic range measuring devices to determine the density and height of a column of foam produced by aeration of the wastewater sample. These data are used to estimate the concentration of AFFF in the wastewater sample. The sensor system can detect concentrations of AFFF as low as 10 parts per million (ppm) in approximately 45 seconds. Solutions containing higher concentrations of AFFF are detected in less time. When the concentration of AFFF exceeds a preset value, a switch within the sensor system is closed. The switch closure can be used to perform functions such as:

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OBJECTIVE

The objectives of this project were to develop and test a sensor capable of detecting the presence of aqueous film forming foam (AFFF) at low concentrations (less than 50 ppm). Desired attributes of the sensor are high reliability, low maintenance, low cost, and small size.

BACKGROUND

Aqueous film forming foam, or AFFF, is a generic name given to a class of chemical compounds that are mixed with water to form a more effective fire fighting agent. AFFF concentrate is added to the water stream being directed at a fire. The resulting mixture forms dense white foam that reduces the amount of air reaching the fire. AFFF is frequently used aboard ships and aircraft crash and rescue vehicles because of its ability to smother liquid fuel fires. As a result of using AFFF in fire fighting training exercises aboard ship (and the unauthorized use of AFFF as a cleaner), the compound sometimes finds its way to the ship's bilge.

When a ship comes into port, it may discharge its bilge water to a shore-side wastewater treatment plant. If the ship's bilge water contains AFFF, the operating conditions of the plant may be upset, resulting in discharges from the plant that exceed the limits of the plant operating permit. There have been incidents where the Navy received notices of permit violation from State environmental agencies for out-of-limit waste treatment plant discharges caused by AFFF.

AFFF is not considered to be toxic to humans, but it can harm small organisms such as the eggs and larvae of aquatic animals. Also, AFFF has been demonstrated to kill beneficial bacteria in wastewater treatment plants. In addition, foam formed by AFFF can cause false readings from flow and level sensors that control waste treatment plant processes. For these reasons, it is very desirable to prevent AFFF from entering a wastewater treatment plant.

If a reliable AFFF sensor system can be developed, it can be used to determine if AFFF is present in the wastewater ships send to a shore-side treatment plant. If AFFF is detected in the waste stream, the wastewater can be diverted to a specialized treatment process or to holding tanks for disposal as a special waste stream.

A prototype AFFF sensor was developed and enclosed in a weatherproof cabinet that measures approximately 2 feet wide by 3 feet high by 8 inches deep (Figure 1). Parts and materials for the system cost approximately $2000.

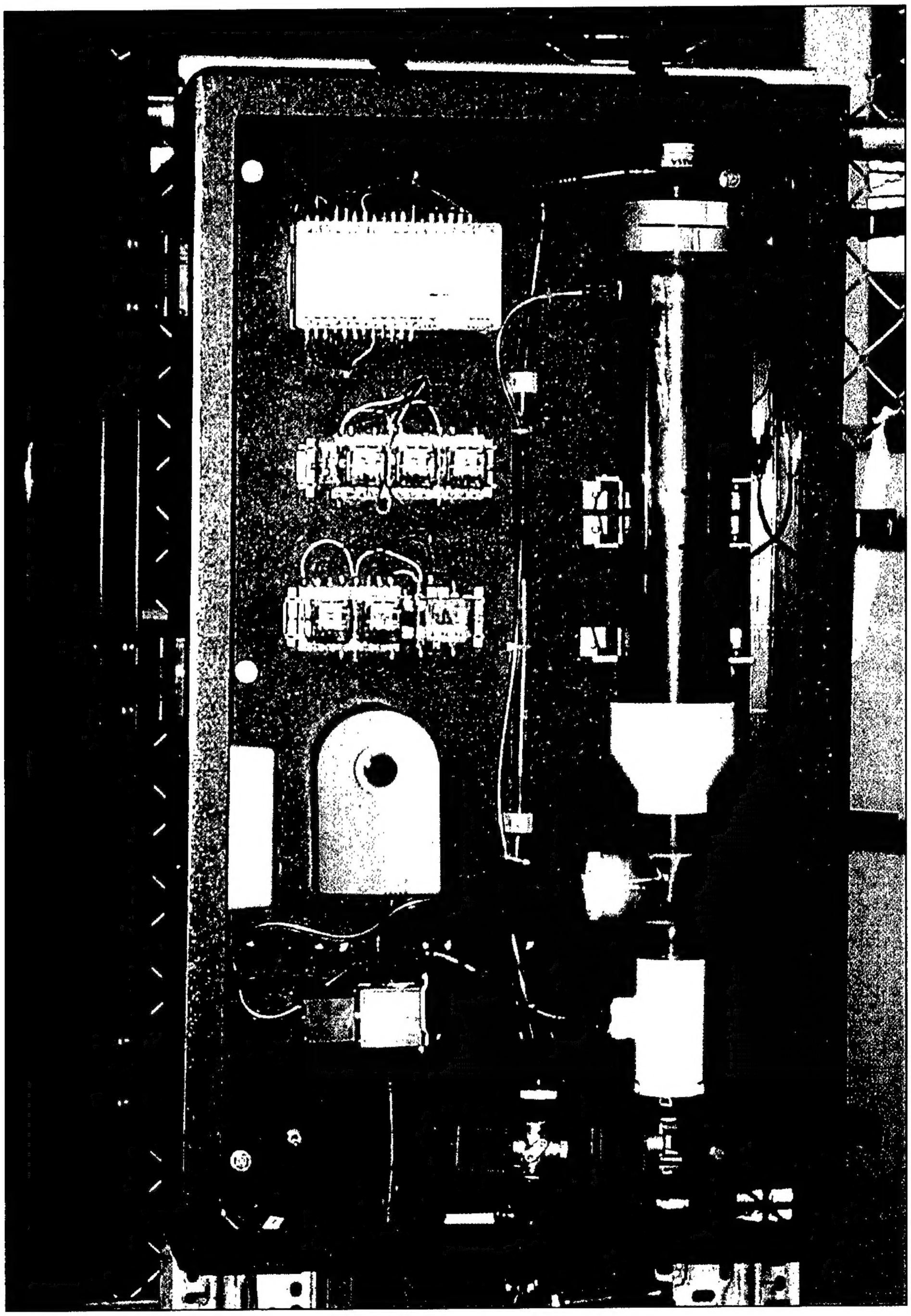

Figure 1. Prototype AFFF sensor unit.

APPROACH

MODEL A SENSOR

An AFFF sensor was designed, fabricated, and extensively tested at the Naval Facilities Engineering Service Center (NFESC). This design, known as Model A, was subsequently installed at the oily waste/waste oil treatment plant at Naval Station (NAVSTA) Mayport, Florida. Figure 2 shows the Model A sensor.

Diagrams of the Model A sensor and a typical installation are shown in Figures 3 and 4. When the bilge water transfer pump comes on, a switch closure activates the AFFF sensor system and begins the testing process. As long as the transfer pump is operating, a small slipstream of wastewater (about 0.3 gallon per minute) flows from the wastewater line to the sensor. The wastewater sample enters the bottom of the sensing chamber through a normally open 3-way solenoid valve.

The sample fills the sensing chamber until it reaches the overflow port in the side of the chamber. The overflow port is connected to a damping chamber. The damping chamber is a horizontal tube with a weir at each end. The damping chamber moderates the flow out of the sample chamber and stabilizes the height of the foam column. (It was discovered during the early experiments that, without the presence of some damping at the discharge port, the height of the foam column would build up to a critical height and then suddenly collapse and discharge through the port. The outlet port damping chamber eliminates this problem.) Discharge from the damping chamber goes to a drain or back to the wastewater line.

An air-stone is used to aerate the sample in the sensing chamber. The air is supplied by a small aquarium air pump. Aeration of the sample forms bubbles in the water. The surfactants in the AFFF adsorb at the water-gas interface and form foam. The column of foam rises, lifting a lightweight, molded polystyrene float. The float serves as a firm target for the acoustic range sensor.

An acoustic range sensor, located at the top of the column, produces pulses of sound at a frequency of 17 kHz. The time it takes for a sound pulse to travel from the end of the sensor to the float and return is measured. From the travel time, the distance from the end of the acoustic sensor to the float can be accurately determined. This distance measurement is compared to three distinct set points: a low set point, a high set point, and an alarm set point. The set point distances and other characteristics of the acoustic sensor are programmed through a serial port on the device using software supplied by the manufacturer.

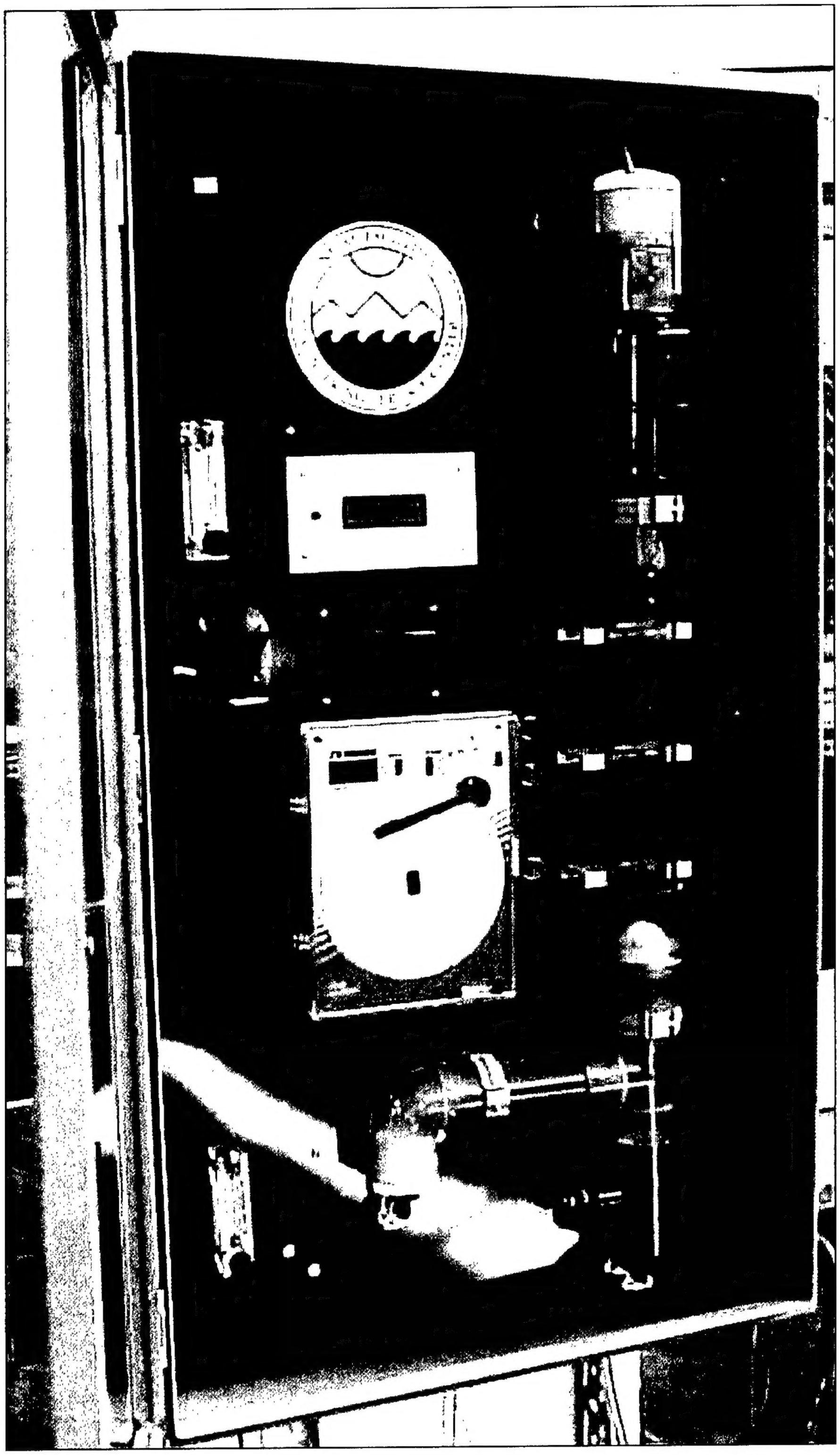

Figure 2. Photograph of the Model A sensor.

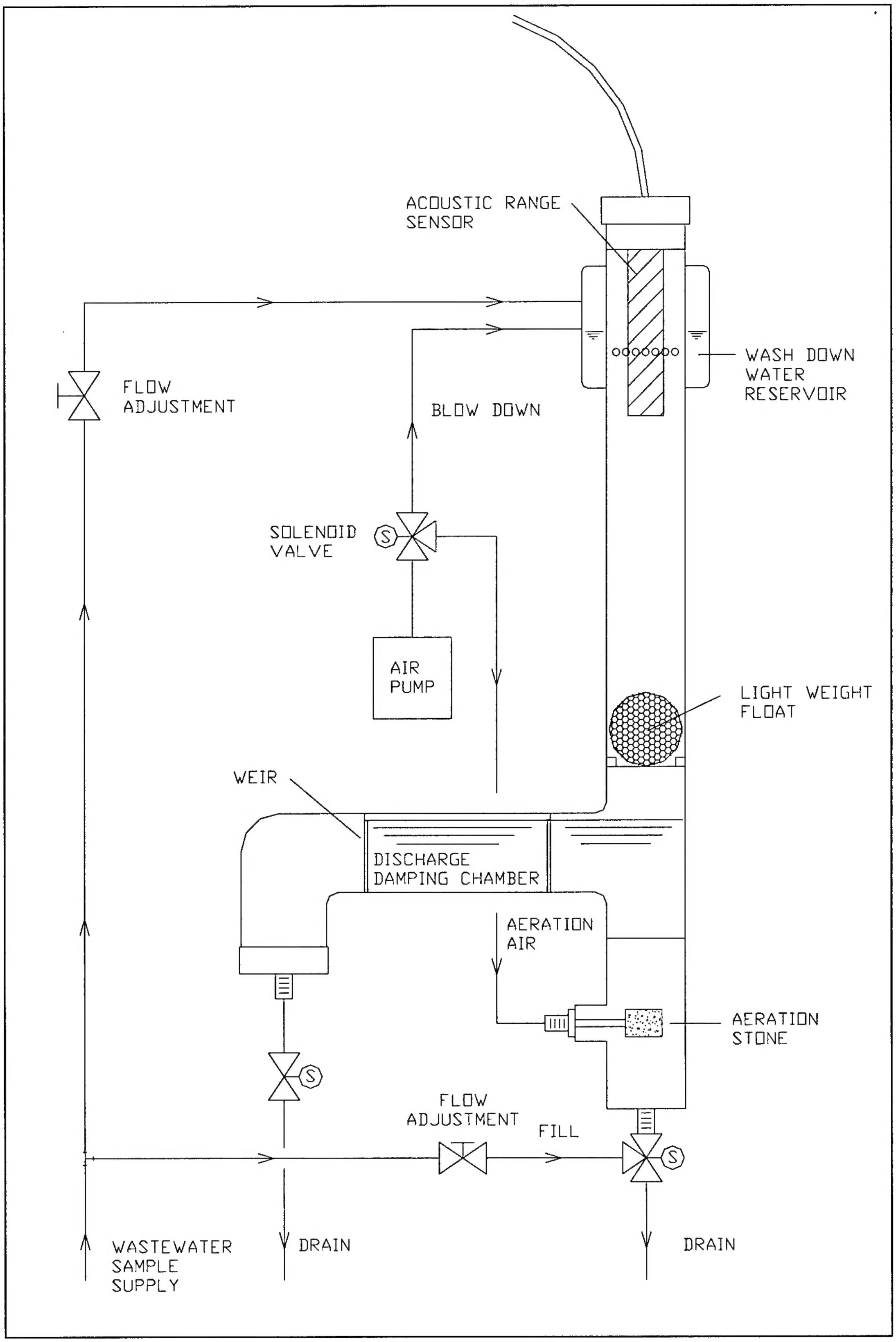

Figure 3. Schematic of the Model A AFFF sensor.

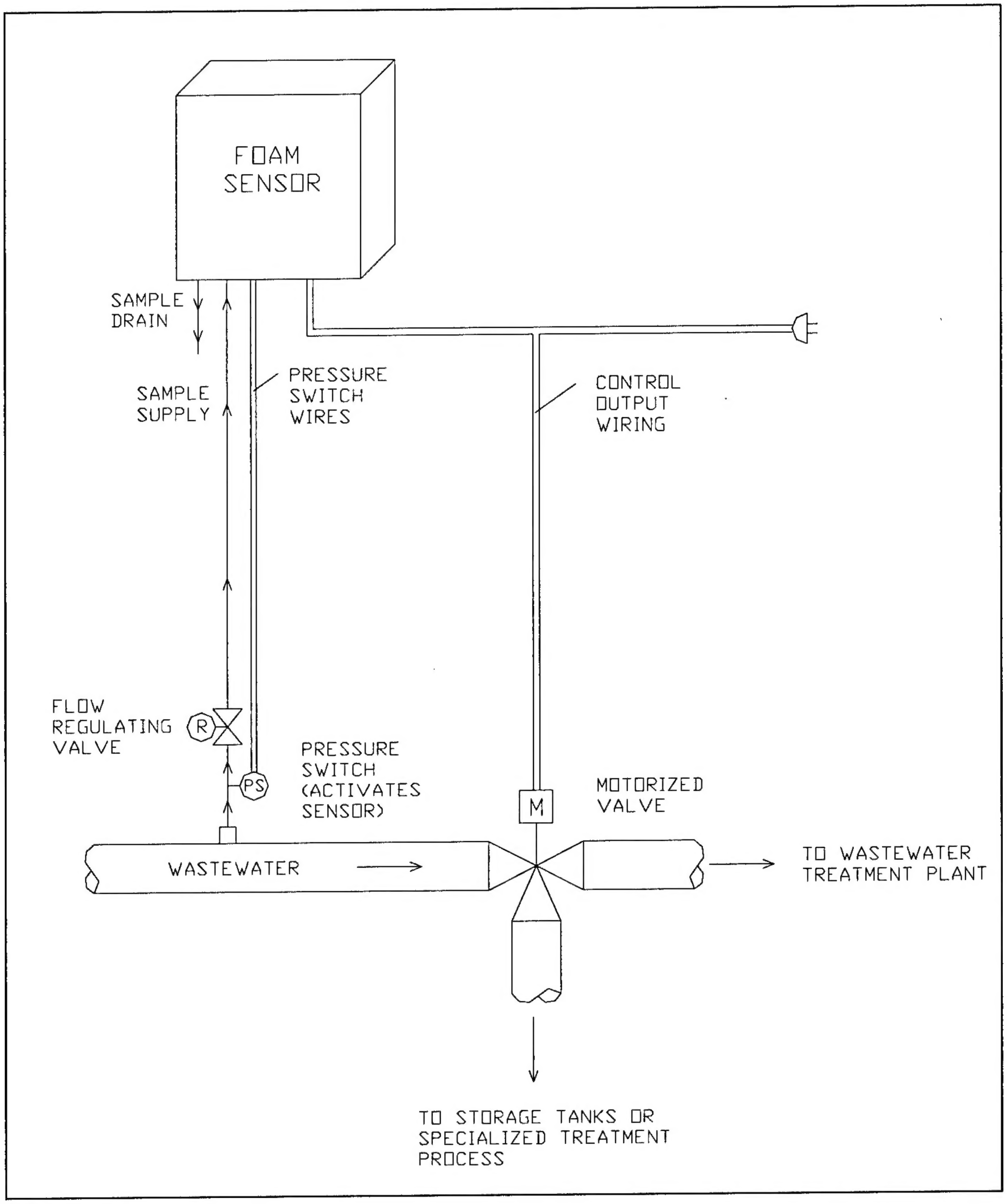

Figure 4. Schematic Diagram of Installation at Oily Waste Treatment Plant.

When the float reaches the high set point, a relay is latched. This switch closure is the output from the AFFF sensor unit and would be used to operate a valve to divert the AFFF laden wastewater away from the wastewater treatment plant. The output relay is unlatched only if the float falls below the low set point and fails to rise to the low set point within a specified period of time. This will occur when the sensor system tests wastewater free of AFFF. If the float rises to the alarm set point, pressurized air is briefly diverted to the top of the sample column. This

action forces the column of foam down to the low set point. When the low set point is reached, air is again directed to the air stone.

The fill and air valves close approximately every 2 minutes. Pressurized air is directed to the top of the sample column. This action forces the column of foam and the wastewater sample out of the sensor. After the sample is purged, the fill and air valves open and the sampling process begins anew. This is the sequential sampling process mentioned earlier.

A small portion of the wastewater sample is directed to a chamber located at the top of the sample column. Within the chamber, the wall of the sample tube is perforated with a series of small holes around the circumference. These holes permit the wastewater sample to run down the interior wall of the sample tube. This "wash down" water helps to keep foam from adhering to the wall of the tube and washes away any particles that may become attached to the interior of the column.

The amount of foam generated under a specific set of conditions depends on:

- The concentration of AFFF in the sample
- How long the sample is aerated
- The rate of aeration air flow

In general, the higher the AFFF concentration, the longer the sample remains in the aeration chamber (i.e., the lower the sample flow rate) and the more air that is forced through the sample, the more foam will be generated. The set point of the AFFF sensor system can be most easily set by adjusting the rate of flow of aeration air. The procedure for setting the sensor to detect concentrations of AFFF above a threshold value is:

1. A solution of AFFF of the threshold concentration is prepared.
2. The aeration air supply is diverted from the air stone by means of a bypass valve.
3. The AFFF solution is then pumped through the sensor system until all parts of the unit contain solution of same concentration.
4. The aeration air bypass valve is then closed until sufficient foam is produced (in the desired response time) to raise the float to the high set point.

The desired response time is the maximum time allowed to detect the presence of foam. For example, it may be the system user's criterion to detect 50 ppm of AFFF within 30 seconds.

To a lesser extent, the set point of the AFFF sensor system can be adjusted by using floats of different weights. Foams formed by low concentrations of AFFF do not have the structural strength to lift a heavy float. It is possible to configure the system so that the float will not lift off its seat at low AFFF concentrations.

The aeration air and wash down do not immediately stop at the end of a sampling operation (i.e., when the bilge water transfer pump stops). Instead, the control system diverts the pressurized air to the top of the sample column for several seconds after the end of sampling. This "blow down" air, coupled with residual wash down water, helps remove any remaining foam from the sample

column. This prevents the target float from being suspended on top a column of residual foam. If the float were to become suspended above the low set point, the system would not shut off.

The AFFF sensor unit is equipped with an event recorder. The event recorder has a circular paper chart that makes one rotation every 31 days. The pen on the event recorder is activated when the AFFF sensor detects foam (i.e., while the output relay is closed). The pen is de-energized when the output relay is opened. The event recorder produces a permanent record of when a "foam event" occurred and how long the event lasted.

A schematic of the wastewater treatment system as NAVSTA Mayport is shown in Figure 5. Lift stations at the piers pump oily wastewater from the piers to the oily waste/waste oil treatment plant, where oil and solids are removed. The discharge from the oily waste/waste oil plant then joins the sanitary wastewater stream (i.e., black water and gray water from the ship's CHT system) at the sanitary wastewater treatment plant. The sanitary wastewater treatment plant is similar to a small municipal sewage treatment plant.

The Model A sensor was installed at the discharge of the oily waste/waste oil treatment plant in April 2000. It was decided to initially install the sensor at the oily waste/waste oil plant because the sensor was thought to be susceptible to plugging by oil, grease, and solids. It was thought that installation of the sensor at the discharge of the oily waste/waste oil plant would minimize the chances of sensor plugging while providing an opportunity to evaluate sensor performance.

The long-term goal was to move the AFFF sensor to a pier-side location. Having the sensor at the pier gives treatment plant operators maximum warning that AFFF is entering the treatment system. When the sensor is located at the oily waste/waste oil treatment plant, detection of AFFF occurs after a significant amount of AFFF contaminated wastewater has already entered the treatment system.

Between April and August 2000, the AFFF sensor at the oily waste/waste oil treatment plant detected and recorded all six releases of AFFF contaminated wastewater. All of these releases were of low AFFF concentration, about 10 to 20 ppm of AFFF. AFFF in this range of concentration does not interfere with the operation of the sanitary wastewater treatment plant, and no corrective actions were taken by plant operating personnel.

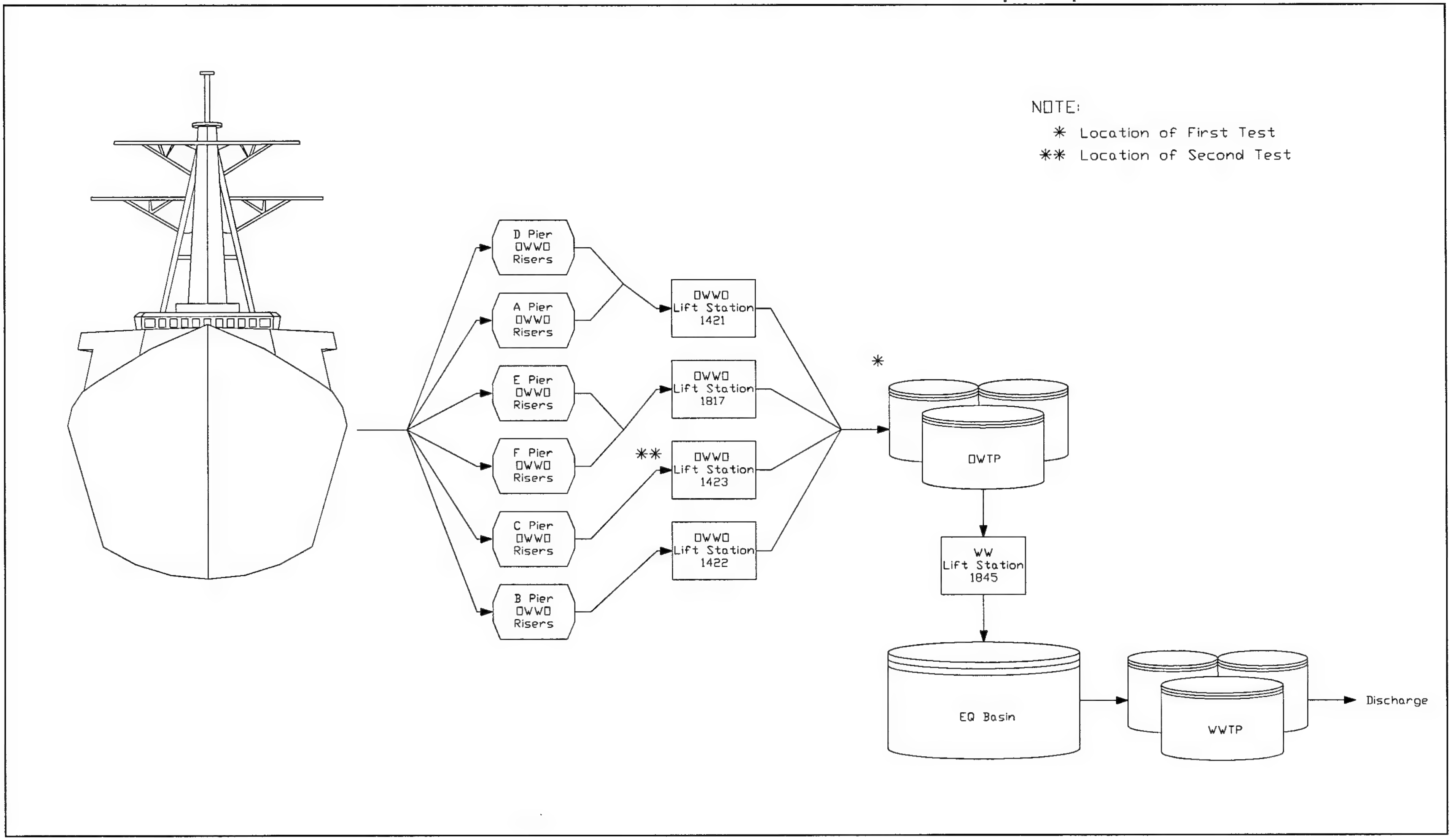

Figure 5. Bilge water treatment process at Naval Station Mayport.

It was reported by plant operating personnel that the sensor had stopped working in mid-August 2000. The malfunction was caused by coagulated oil and, possibly, algae plugging the sensor. When only small amounts of oil are present in the influent waste stream, the oily waste/waste oil treatment plant removes the oil by dosing the influent stream with chemicals that cause the oil in the water to coalesce into a loose, flocculent, coagulant. Sand filters at the sanitary wastewater treatment plant remove the coagulated oil. The flocculent (described as large, thin, sheets of black "slime") collected in the outlet of the AFFF sensor and restricted draining of the sample from the sample chamber. Eventually, the sample inlet flow rate exceeded the sample outlet flow rate. As a consequence, wastewater accumulated in the sample cylinder to a level were it damaged the ultrasonic range sensor.

The Model "A" AFFF sensor was removed and salvaged for parts.

MODEL B SENSOR

After analyzing the failure of the Model A sensor, a new AFFF sensor was designed, built, and tested at NFESC. This new sensor (Model B) was designed to minimize the potential for plugging by:

- Replacing the gravity drain used in model A with a forced discharge of the wastewater sample
- Eliminating all flow control valves in the sensor
- Minimizing the number of plumbing fittings and other flow restrictions.

A schematic diagram of the Model B sensor is shown in Figure 6. A photo of the sensor is shown in Figure 7. Figure 7 shows the sensor connected to a laptop computer so that the operation of the programmable logic controller can be monitored. Note the AFFF foam in the sensor column.

The Model B sensor also incorporates a larger diameter sample tube. A larger diameter tube results in a smaller size sensor and simplifies the implementation of sample fill and wash-down.

The Model B sensor also incorporates a communication capability. When AFFF is detected or a maintenance action is required, the sensor dials either a pager or a computer terminal and displays the appropriate message to the treatment plant operators. The operators can then take action to remedy the problem. Communications capability is required when a sensor is installed at a pier lift station, as no one will normally be present at these locations to see or hear an alarm indicator.

In addition to modifications to the foam sensor unit, provisions were made to remove free oil and solids from the wastewater sample stream.

The sample preparation system evaluated consists of a backwash strainer to remove large solids, followed by a filter. The filter element is made of cellulose that has been treated to have an affinity for oil. The input stream is periodically directed backwards though the strainer to wash

accumulated solids from the strainer element. The period and duration of the backwash are controlled by the PLC in the foam detector. If the oleophilic filter element becomes plugged, a maintenance alert is transmitted to the operating personnel.

A photograph of the sample cleaning system is presented in Figure 8.

The sample handling uses a small pump to transfer the discharge of the sensor to a drain. The sensor installation at the oily waste/waste oil treatment plant depended on gravity drains. Due to inherently low flow velocity, these gravity drains are prone to plugging by deposits on the piping walls. A discharge pump eliminates this problem and can accommodate variations in component elevations. The discharge pump is operated by a latching relay that starts the pump when the level in the sump is nearly full, and stops the pump when the sump is nearly empty.

The sump vessel and sump pump are shown in Figure 9.

The Model B AFFF sensor was installed at the bilge water lift station (Building 1423) on "C" pier in April 2001 (Figure 10). A photograph of the installation is shown in Figure 11.

A diagram of the installation at the lift station is presented in Figure 12.

A Supervisory Control and Data Acquisition (SCADA) system is installed at NAVSTA, Mayport. Rather than use the communications capability built into the AFFF Model B sensor, it was decided to use the capabilities of the existing SCADA system. Telephone lines to Building 1423 connect the SCADA system to the wastewater plant operators located several miles away. The original purpose of the SCADA installation at Building 1423 was to monitor the operation of two large wastewater transfer pumps. Two additional digital inputs to the SCADA remote terminal unit were installed - one to report a foam event and one to report a maintenance requirement.

The model B AFFF sensor has been functioning without failure since its installation.

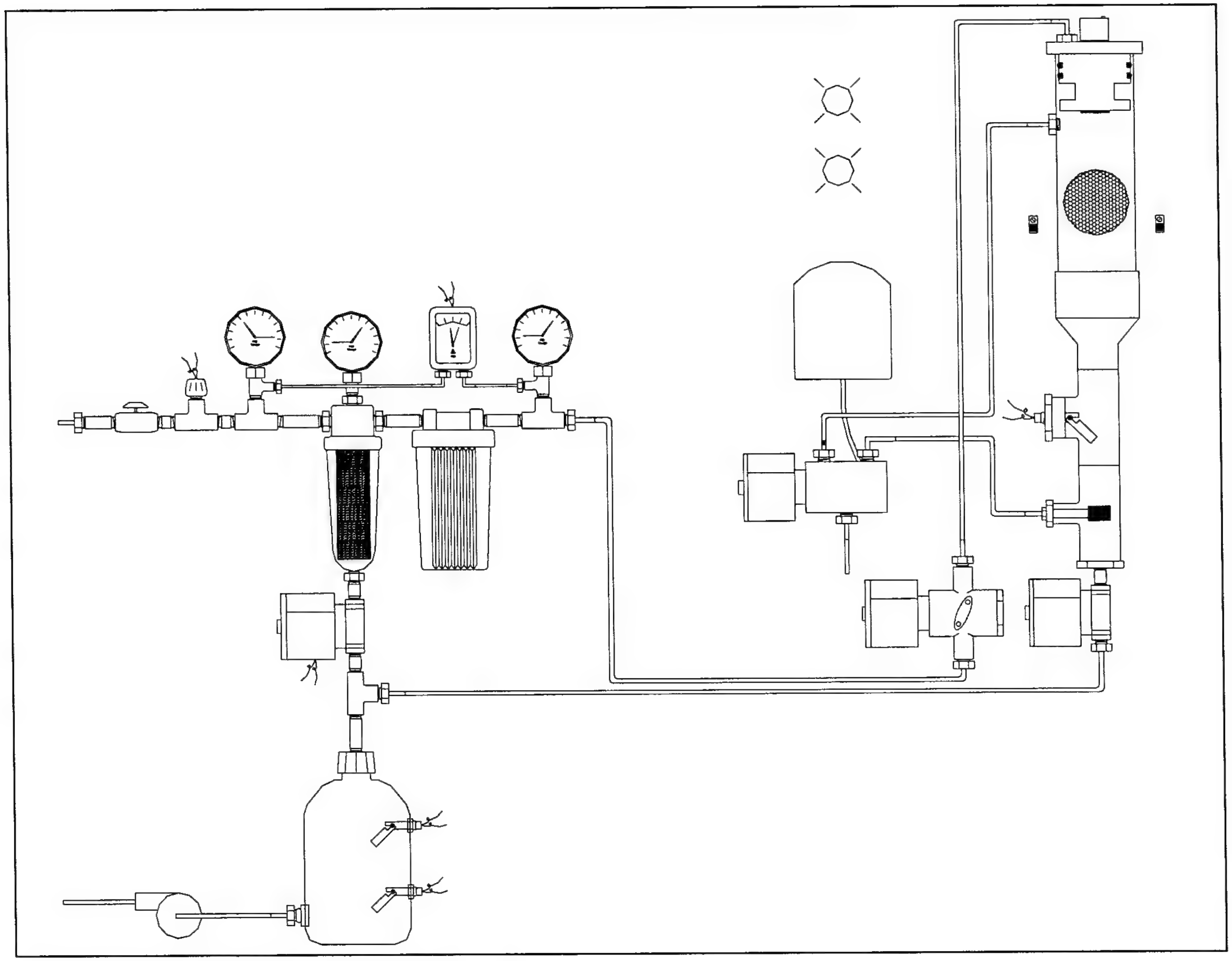

Figure 6. Schematic diagram of AFFF Model B sensor.

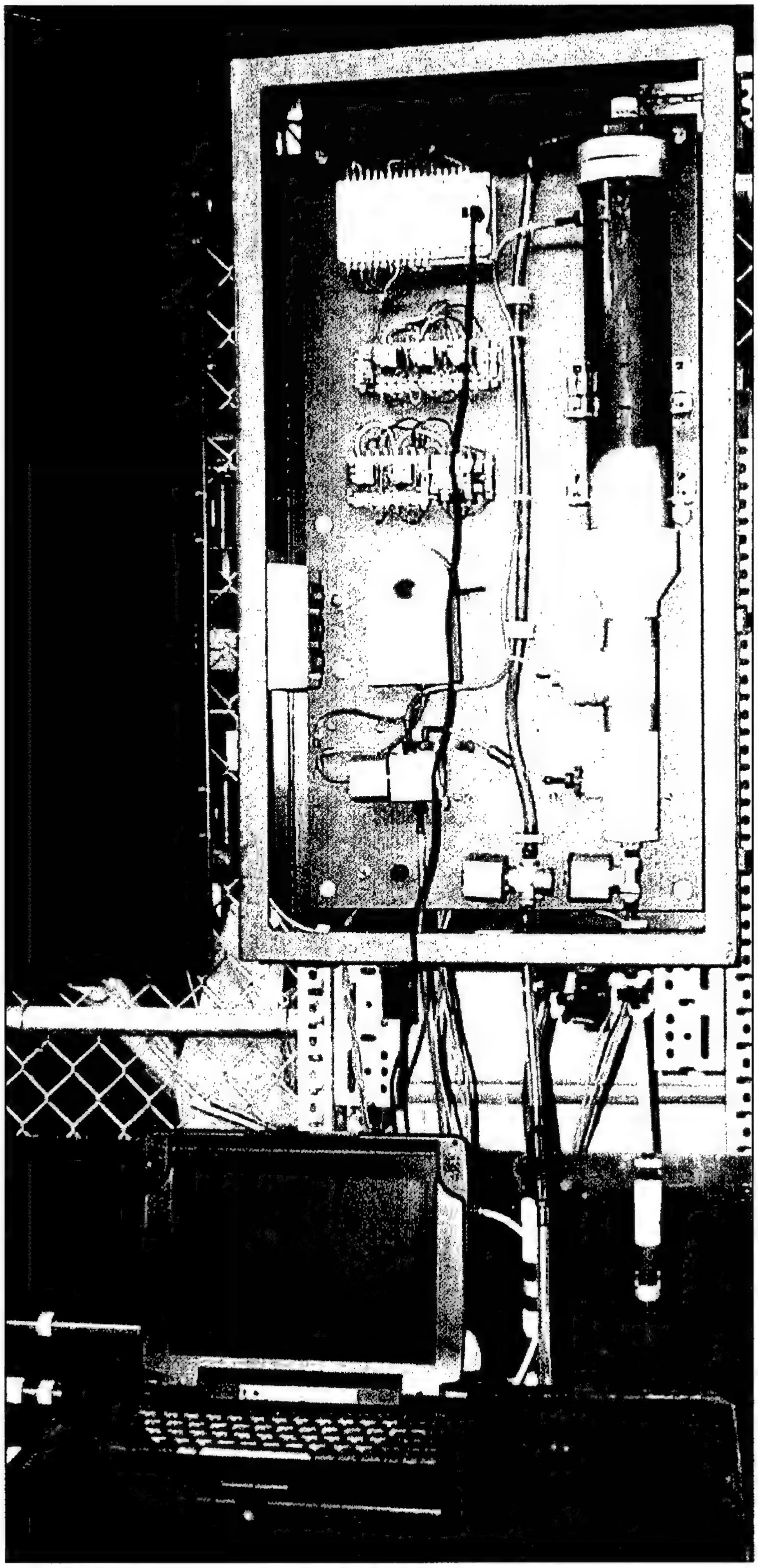

Figure 7. Photograph of the AFFF Model B sensor.

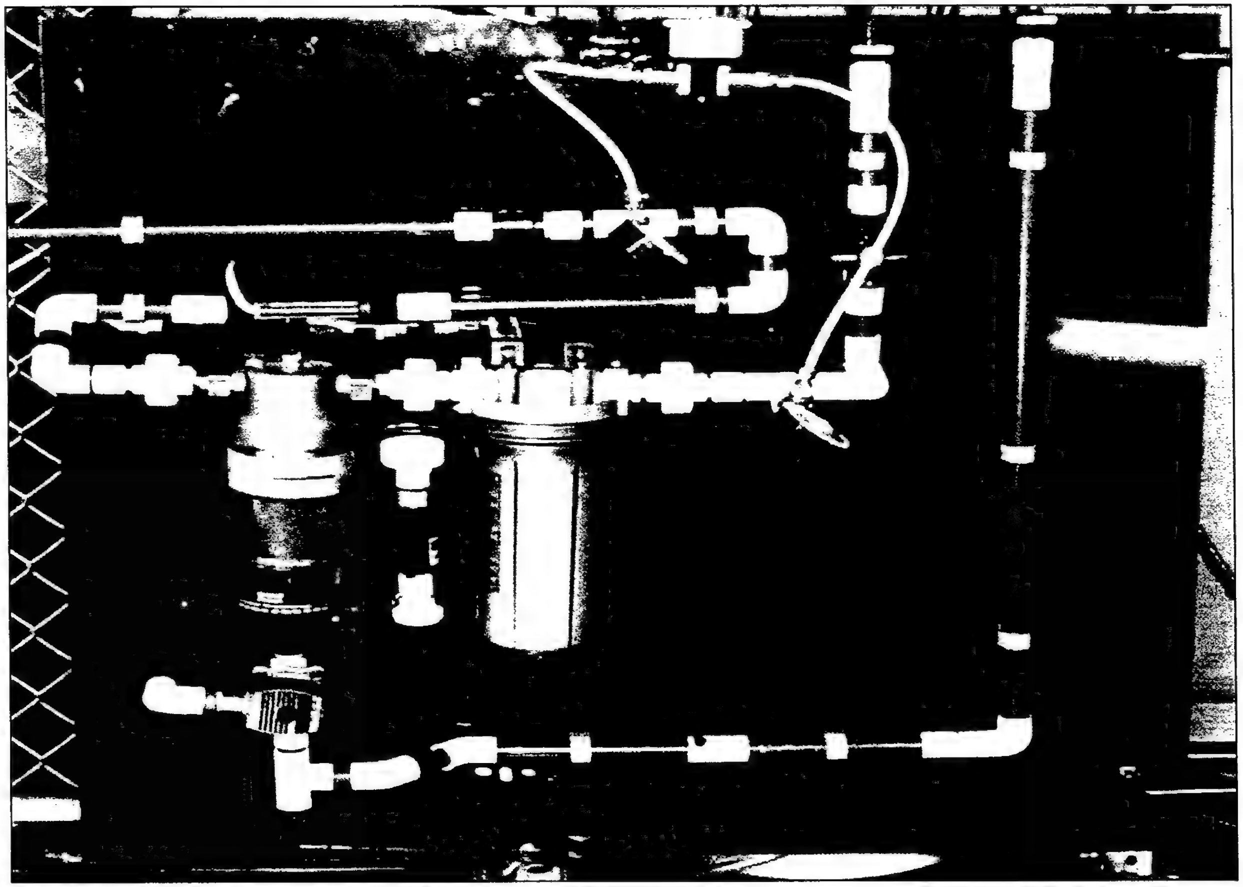

Figure 8. Photograph of wastewater sample cleaning system.

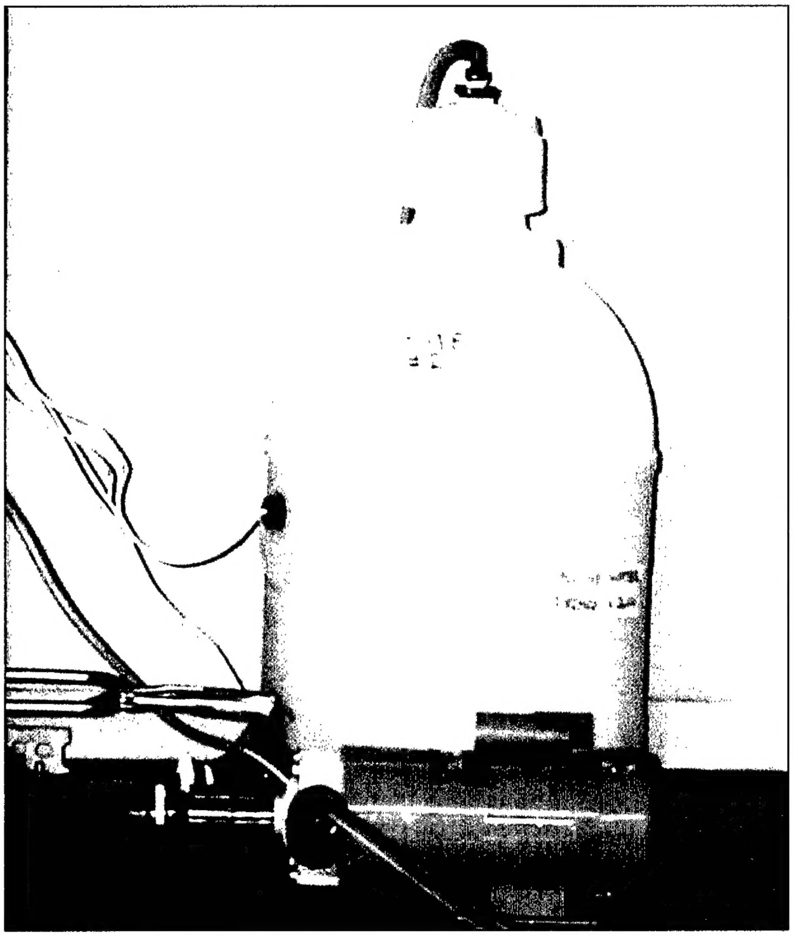

Figure 9. Photograph of sump vessel and sump pump.

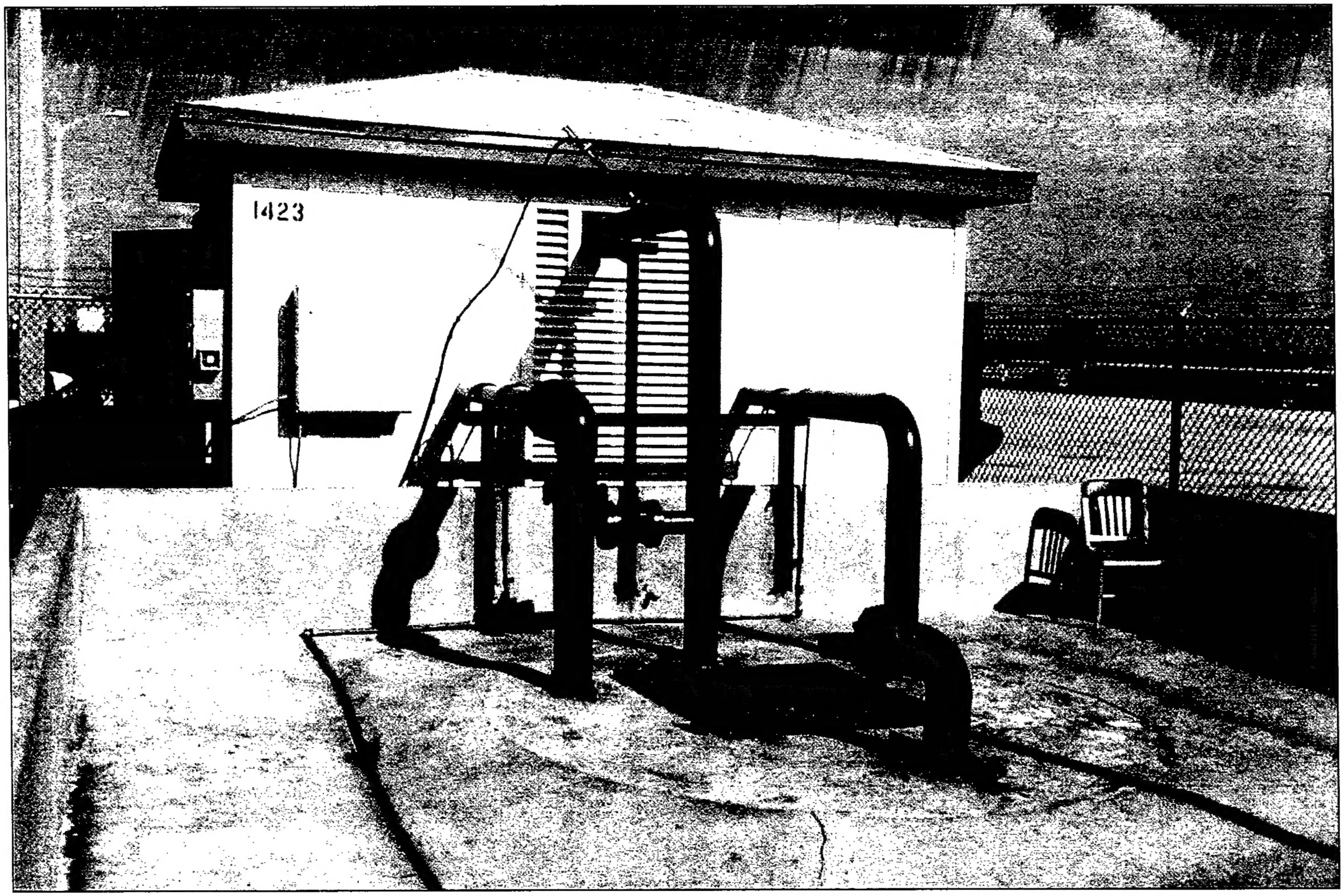

Figure 10. Bilge water lift station on "C" Pier, Naval Station Mayport.

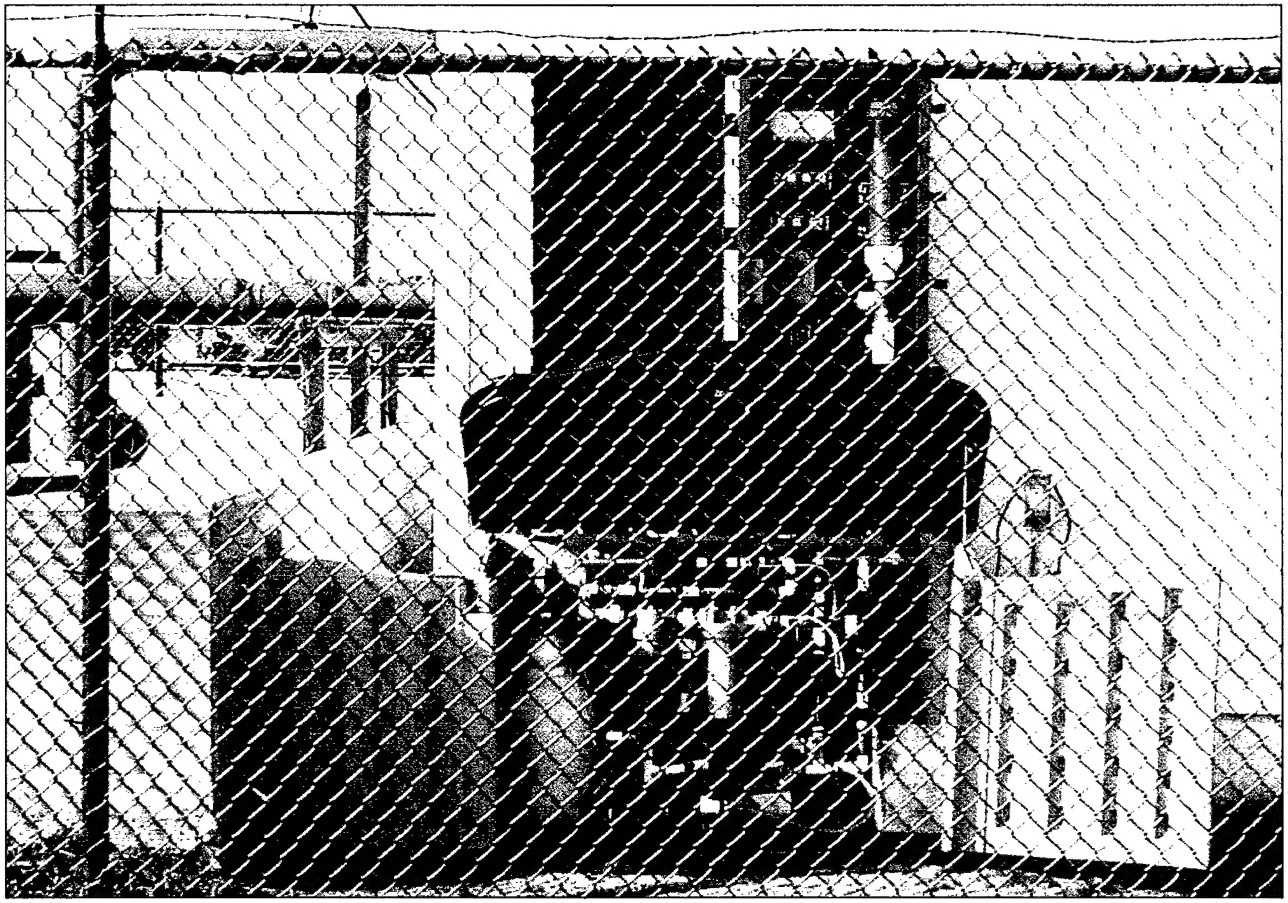

Figure 11. Installation of the AFFF sensor and sample cleaning system.

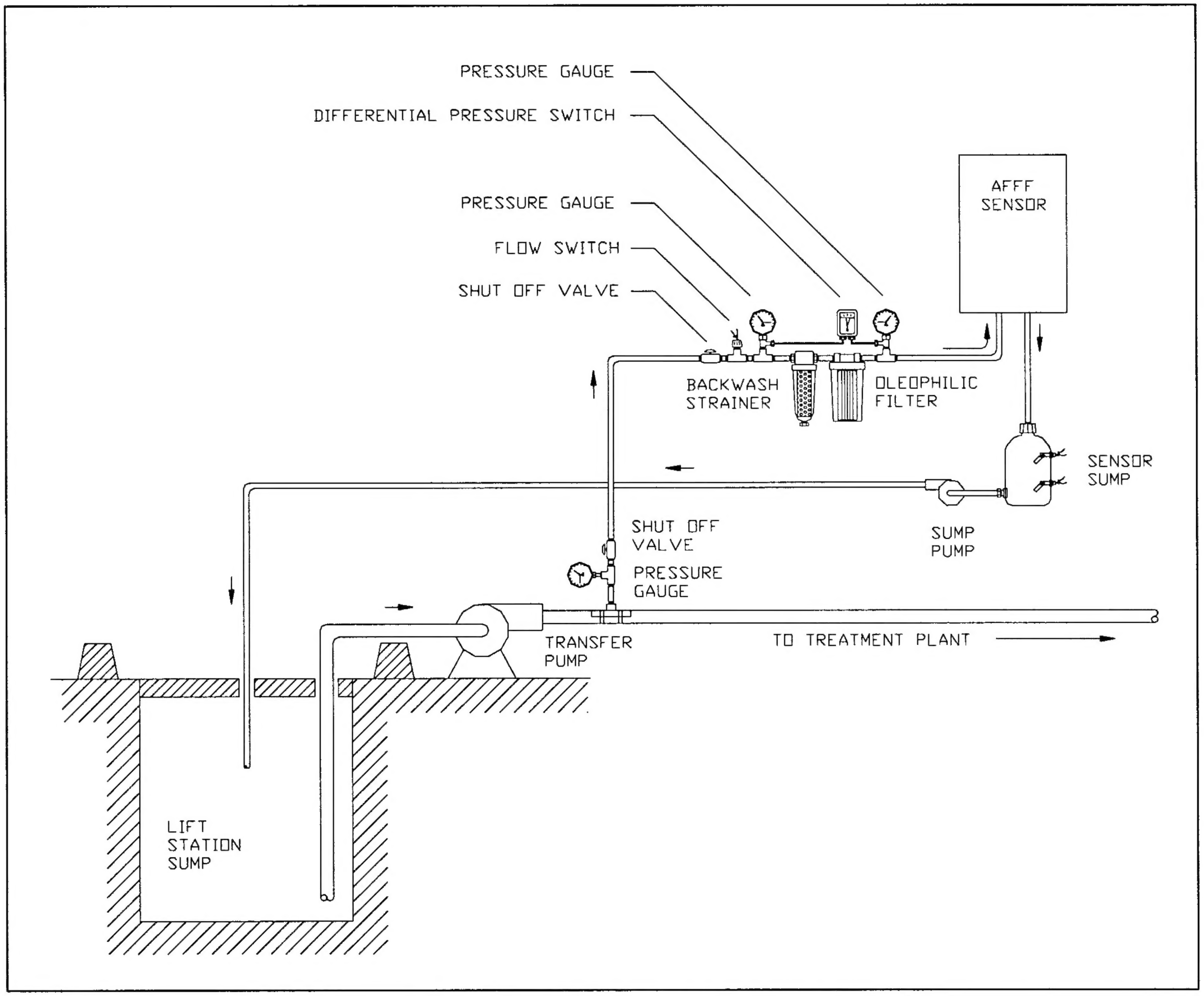

Figure 12. Schematic of installation at lift station.